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RESEARCH ON AN AUTOMATED INERTIAL AZIMUTH MEASURING SYSTEM

William D. Atwill

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Chestnut Hill, MA 02167

November 1978

Scientific Report No. 1

AIR FORCE GEOPHYSICS LABORATORY
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Requirements for highly precise azimuth references for USAF weapons systems have led to an improved automated azimuth measuring system (AAMS). The AAMS represents the state-of-the art for a highly accurate, automated, all-weather azimuth capability which can be used in either a laboratory or specialized field environment. The present system consits of two integrated

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inertial sensors, an angle transfer system, a tiltmeter array and a microprocessor. The inertial sensors use gimbal-mounted rate gyrocompasses to indicate the azimuths of two transfer mirrors with respect to true North. The azimuths are transferred to any number of reflectors by an autocollimator on a precision indexing table. Sight tubes carry low velocity air along each optical path. Highly sensitive tiltmeters are used to measure and correct for errors due to base motions of the inertial sensors. Data handling and functional operation are controlled by the microprocessor. Recent results indicate a standard deviation of 2.1 arc seconds for a single observation. Proposed improvements include refined support electronics, improved measurements of tilts of the gyrocompasses, increased automation and more extensive software for signal processing.

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I. INTRODUCTION

With the improvement of weapons system technology, the problems of providing high-accuracy azimuth references in both ICBM test facilities and operational environments have become increasingly significant. Azimuth uncertainties now represent a substantial portion of the total ICBM weapons system Circular Error Probable (CEP) estimates.

Efforts within the Department of Defense to improve azimuth accuracy have been concentrated in two general categories. First is improvement of instrumentation and techniques associated with measuring azimuth. Second is the evaluation of the effects of local and regional crustal motions on the stability of long term azimuth references and on azimuth measuring instrumentation.

1.1 State of the Art

The aerospace industry has traditionally relied upon stel ar observations to determine the azimuths of precise geodetic references. However, astro-optical azimuth techniques have significant drawbacks. Typically, a large number of observations taken over a period of months to years are required to develop an accurate data base. Observations require optimum weather conditions in order to see the reference star. Field data must be reduced using star position catalogs, and then corrected for such effects as polar motion. Effects from such phenomenon as refraction due to the earth's atmosphere are still uncertain.

Estimates of uncertainties associated with stellar azimuth measurements do appear to be quite small. However, these estimates can be misleading. Typically, an estimate of uncertainty is expressed as the standard error of the mean or of a "least squares" linear fit of the data. Thus, as the number of observations is increased, the estimate of the uncertainty will usually decrease. But these statistical estimates do not account for the fact that most stellar azimuth observations are made at night. As a consequence, any motions of the azimuth reference device having periods shorter than 24 hours will not appear in the mathematical estimate of the azimuth uncertainty.

1.2 Inertial Azimuth Systems

In recent years, numerous government and commerical agencies have been using inertial measurement systems for practical geodetic applications.[1] These inertial azimuth systems have a number of advantages over traditional astro-optical methods for establishing azimuth references. They are not affected by such traditional restrictions as weather fluctuations, requirements for darkness during observation periods, human observation errors and errors associated with azimuth transfer from the outside astronomical reference to the desired indoor reference. A further advantage of inertial systems is the increased observation frequency which assures a more complete description of the higher frequency motions of the azimuth reference.

However, an inherent disadvantage of most inertial azimuth measuring systems is that they cannot distinguish between sensing earth rate and sensing rates due to tilt motions. The Air Force Geophysics Laboratory (AFGL), in conjunction with Boston College, has investigated the effects of tilt motions on inertial sensors and determined that the accuracy of inertial azimuth measurements can be significantly improved by measuring and correcting for the errors due to tilts and tilt rates.

This principle is employed in the automated azimuth measuring system (AAMS). The system, described herein, was developed to meet the specialized requirements of testing and evaluation of Air Force weapons systems. It it especially suitable for use in indoor environments where highly accurate azimuth references are required and access to a stellar reference is restricted.

II. SYSTEM DESIGN

The AAMS is comprised of two service test model Azimuth Laying Sets (ALSs), which inertially determine azimuth; an inductosyn/autocollimator azimuth transfer system; a tiltmeter array and a microprocessor. A plastic enclosure with controlled airflow is used to reduce thermal gradients near the AAMS, and sight tubes with forced air are used between the AAMS and the target to reduce refractive bending of the lines of sight. The system is pictured in Figure 1.

2.1 Azimuth Laying Sets

The ALSs are the primary azimuth measuring components of the AAMS. Each ALS is comprised of a geosensor -- which uses four-position gyrocompassing to determine the orientation of its input axis with respect to true North, and a control indicator -- which controls the operation of the geosensor and displays the input axis misalignment from true North. The two ALSs are synchronized, thereby providing two simultaneous azimuth estimates.

The primary component of the geosensor is the rate-sensing gyrocompass. The gyro has three orthogonal axes -- spin, input and output -- which are supported on two gimbals. A small mirror is mounted approximately perpendicular to, and on each end of the North-South gimbal for the purpose of azimuth transfer. The gimbal arrangement allows for rotating and inverting the gyrocompass into four orientations, there-

FIGURE 1. Automated Azimuth Measuring System

by cancelling potential systematic errors.

In a typical operational arrangement, the axes are aligned as follows: the spin axis (SA) is approximately north-south; the input axis (IA) is approximately east-west; and the output axis (OA) is up or down.

Earth rate, sensed as a torque about the IA, is balanced by a known torque applied about the OA. The value of the balancing torque is proportional to the component of earth rate acting upon the IA, thus providing a measure of the orientation of the IA with respect to the earth's spin axis. By aligning the IA as closely as possible to east or west, the component of earth rate being sensed by the IA is minimized (exactly east or west results in no torque about the IA) and the sensitivity to small changes in input rate can be increased. Accordingly the system's azimuth resolution is increased as well.

The component of earth rate being sensed by the gyrocompass is also a function of the cosine of the latitude of operation. This latitude term is automatically incorporated in the balancing loop by application of a variable voltage scale factor to the balancing torque. The scale factor is determined by calibrating a potentiometer setting on the ALS control indicator while moving the alignment of the geosensor IA through a known angle.

A single AAMS azimuth determination is referred to as a "sequence". During any given AAMS sequence earth rate is sampled with the ALS gyrocompass alternately aligned into the four positions of input axis east or west, and output axis up or down to eliminate systematic errors. These four sample positions are called "measurement positions". As the gyrocompass orientation is changed, the polarity of the torque about the input axis due to earth rate is also changed. Thus at the end of each sequence the four samples are summed, and the result is displayed by the ALS. Except for a small bias error which is determined during calibration, this result represents the true azimuth of the ALS mirror normal as long as there has been no tilt of the IA during the measurement position. However, this is not normally the situation.

2.2 Tiltmeters

The earth rate component being sensed by the gyrocompass, and therefore the azimuth estimate, is affected by tilt in two ways. First, if the static tilt (i.e. level) of the gyrocompass is changed, the component of the earth rate vector which acts on the IA will also change. Second, the gyrocompass cannot distinguish between earthrate and tilt rates being sensed by its IA. Thus, if the tilt of the IA varies during any measurement position, the resulting tilt rates will be interpreted by the gyrocompass as earth rate. The significance of these tilt effects is further discussed in Section IV.

In its present configuration, tilt of the ALS geosensor is measured by an array of orthogonal tiltmeters, and corrections for tilt and tilt-rate effects are applied to the azimuth data. Six Radian C-4 tiltmeters are orthogonally placed near the base of each of the ALS geosensors, thus approximating motions of each gyrocompass IA with base motion measurements. However, as a part of an accuracy improvement program now in progress, tiltmeters will be installed inside the geosensors across the gimbal axes to better represent the actual tilts being sensed by the gyrocompasses. Tilt and tilt rate corrections are presently applied after-the-fact during data reduction. This process will be automated, and real-time corrections applied in the future. These improvements are discussed in Section V.

2.3 Azimuth Transfer

Azimuths are transferred from the ALS geosensors to the desired target by combining the horizontal angle between each geosensor and the target with the respective ALS azimuth. The required angles are determined by slewing an autocollimator mounted on an inductosyn indexing table between each of the mirrors once during every measurement position. The inductosyn slew is commanded by the microprocessor and is triggered when the microprocessor receives a "servos null" signal from the ALS.

A predictor scheme is employed to position the inductosyn so that each time the autocollimator is slewed, it is positioned nearly normal to the particular mirror it is sampling. A servo loop is then activated, allowing the autocollimator to null on the target by further slewing the industosyn table. The final position of the inductosyn table at the target is combined with the inductosyn table position for each of the ALS geosensor mirror observations to determine the angle between the target and the ALS. These angles are then combined with their respective ALS azimuth estimates to arrive at two redundant estimates of each target azimuth. Each new target orientation is then used as a predictor for the next measurement position, and the entire cycle is accomplished once again.

2.4 Data Collection and Operational Control

An LSI-11 microprocessor is presently employed to control operation of the ALS and inductosyn/autocollimator angle transfer system. In addition, the LSI-11 acts as an input/output device for all data handling and operator control commands. Data ia accumulated in the LSI-11 memory and then periodically dumped on magnetic tape. Analog data is digitized and filtered by the microprocessor prior to storage. Data reduction is then accomplished after the fact in the laboratory.

Proposed modifications to this procedure are discussed in Section V. These modifications will enable real-time data processing and limited analysis through additional microprocessors.

III. SYSTEM ACCURACY

Azimuth accuracy of the AAMS is dependent upon both the system's repeatability (or relative accuracy) and bias (or absolute accuracy).

Laboratory and field data have been statistically analyzed to determine the repeatability of the AAMS. The standarad deviation of a single AAMS determination (4 sequences) is approximately 2.1 arc seconds. The standard error of the mean is 0.6 arc seconds. These statistics were determined by combining the standard deviations from multiple sets of 4 hours of tilt- and tilt-rate corrected data. Four hours of data (12 points) was chosen to get a maximum number of points while minimizing the likelihood of motion of the observed target.

To arrive at the absolute accuracy of the AAMS one must simply apply a bias to each determination. The bias would be determined by calibrating the AAMS against an azimuth standard. The true uncertainty of a single AAMS observation would then equal the root sum square of relative AAMS variance and the variance of the azimuth standard.

An approximation of the bias of the two ALSs was obtained by making repeated azimuth determinations in the ALS certification room at the Aerospace Guidance and Metrology Center (AGMC), Newark AFS, Ohio, in January and February of 1976. These data are tabulated in Table 1. Each mean in the table consists of five 4-position ALS sequences. The ALS geosensor was leveled at the start of each set to within approximately 0.2 arc sec using the built-in geo-sensor bubble. Tilts and tilt rates were not measured. Thus it is possible that the mean azimuths could be in error by more than an arc second. (A detailed discussion of tilt and tilt rate effects on the ALSs is presented in Section IV.)

A more precise evaluation of the absolute accuracy of the AAMS is programmed for the early fall of 1978. The AAMS will be referenced to two optical cubes located in the ALS verification facility at F.E. Warren AFB, Wyoming. The AAMS data will be compared with repeated astronomic azimuth observations and ALS certification data which is available from the Defense Mapping Agency Geodetic Survey Squadron. In addition, tilt will be measured on the monolith which supports the azimuth reference in order to further characterize the azimuth motions of the reference cubes during the AAMS calibration.

Table 1. ALS Certification Summery

ALS 1			ALS 2		
MEAN*	STND DEV	STND ERROR OF MEAN	MEAN*	STND DEV	STND ERROR OF MEAN
179°59' 58"28	1.29	0.58	179°59' 54"90	1.77	0.79
58"72	0.83	0.39	53"58	1.51	0.68
61"62	1.15	0.51	53"18	4.90	2.19
61"40	1.62	0.72	54"80	2.58	1.15
59"96	1.22	0.55	52"06	2.27	1.02
59"44	1.21	0.54	52"86	1.20	0.54

GRAND MEAN	STND ERROR OF GRAND MEAN	GRAND MEAN	STND ERROR OF GRAND MEAN
179° 59' 59".90	0".31	179° 59' 53".56	0".48

REFERENCE CUBE	DIFF	REFERENCE CUBE	DIFF
179° 59' 55".70	-4".20	179°59' 56".90	+3".34

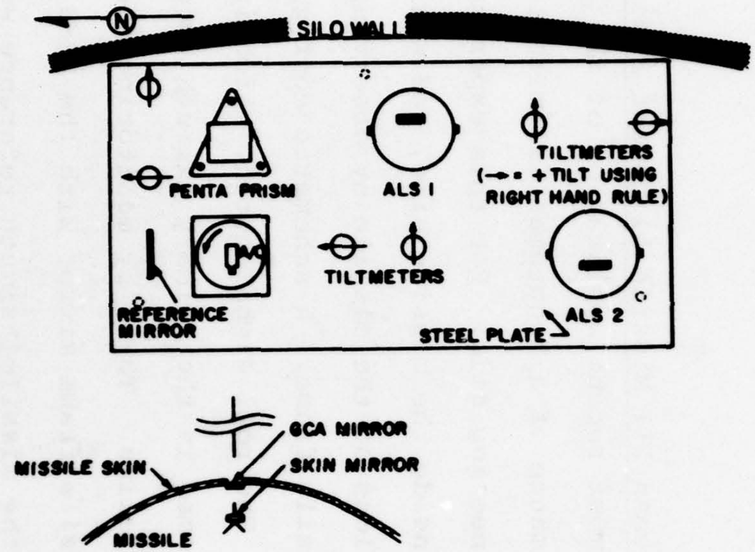
*Corrected for North-South tilt. Tilt rate about the input was not measured. Each mean is computed from five 4-position ALS sequences.

IV. APPLICATIONS

The AAMS is ideally suited for high-accuracy indoor azimuth measurements where access to celestial references is restricted. Because of its portability and size, it can be utilized in confined environments or it can be adapted to large laboratories where multiple azimuth references are desired.

4.1 Minuteman III Missile Alignment Experiment[3]

The most recent application of the AAMS was to verify the performance of a Minuteman III missile guidance system in an engineering silo. For this experiment, the AAMS was operated inside the missile silo, and was used to track relative motions of the missile by observing a mirror attached to the missile frame. A schematic configuration is shown in Figure 2. The roll gimbal notch, which is attached to the mis: ile frame, is the primary azimuth reference for Minuteman III missiles. Thus, by monitoring the relative motions of the missile frame mirror with the AAMS, the motion characteristics of the missile azimuth reference were defined. Motion scenarios observed during the experiment include missle nozzle tests, missile inertial measurement unit calibrations, two distant earthquakes and motions due to thermal variations. These data were then compared with azimuth alignment data from the onboard gyrocompass assembly (GCA). The GCA data reflects how the missile guidance set interpreted the mo-



MISSILE ALIGNMENT
EXPERIMENT

FIGURE 2

tions of the azimuth reference. The comparison of the two sets of data therefore provided a means for evaluation of the effectiveness of the missile in maintaining its azimuth orientation under various motion scenarios.

Typical performance data from the AAMS are shown in Figure 3. Figure 3a shows the AAMS data, uncorrected for tilt and tilt rate errors, during a weekend interval when the silo was unoccupied. Note the presence of the apparent diurnal period in the azimuth estimate.

Figure 3b shows the corrections for the effects of tilt and tilt rate which were applied to the raw ALS azimuth estimates. These corrections were determined by computing the theoretical effects of the measured tilts on the ALS gyrocompasses at 41°N latitude. For this application, a tilt error of 1 arc second caused an 0.87 arc second azimuth error. A tilt rate of only 0.2 arc seconds per hour induces a 1.0 arc second gyrocompassing error.[3] From the Figure, one can see that most of the apparent diurnal motion observed in the raw ALS azimuth estimates resulted from tilt rate errors. These tilt rates were caused by solar heating of the ground surrounding the silo. The tilt correction, however, exhibits a long period trend of nearly 4 arc seconds. This correction resulted from a gradual tilting of the silo collimator bench (which served as a support for the AAMS) due to a rise in the ambient silo air temperature.

Application of the combined tilt and tilt rate corrections to the raw azimuth estimates results in the actual missile mirror azimuth time history shown as Figure 3c.

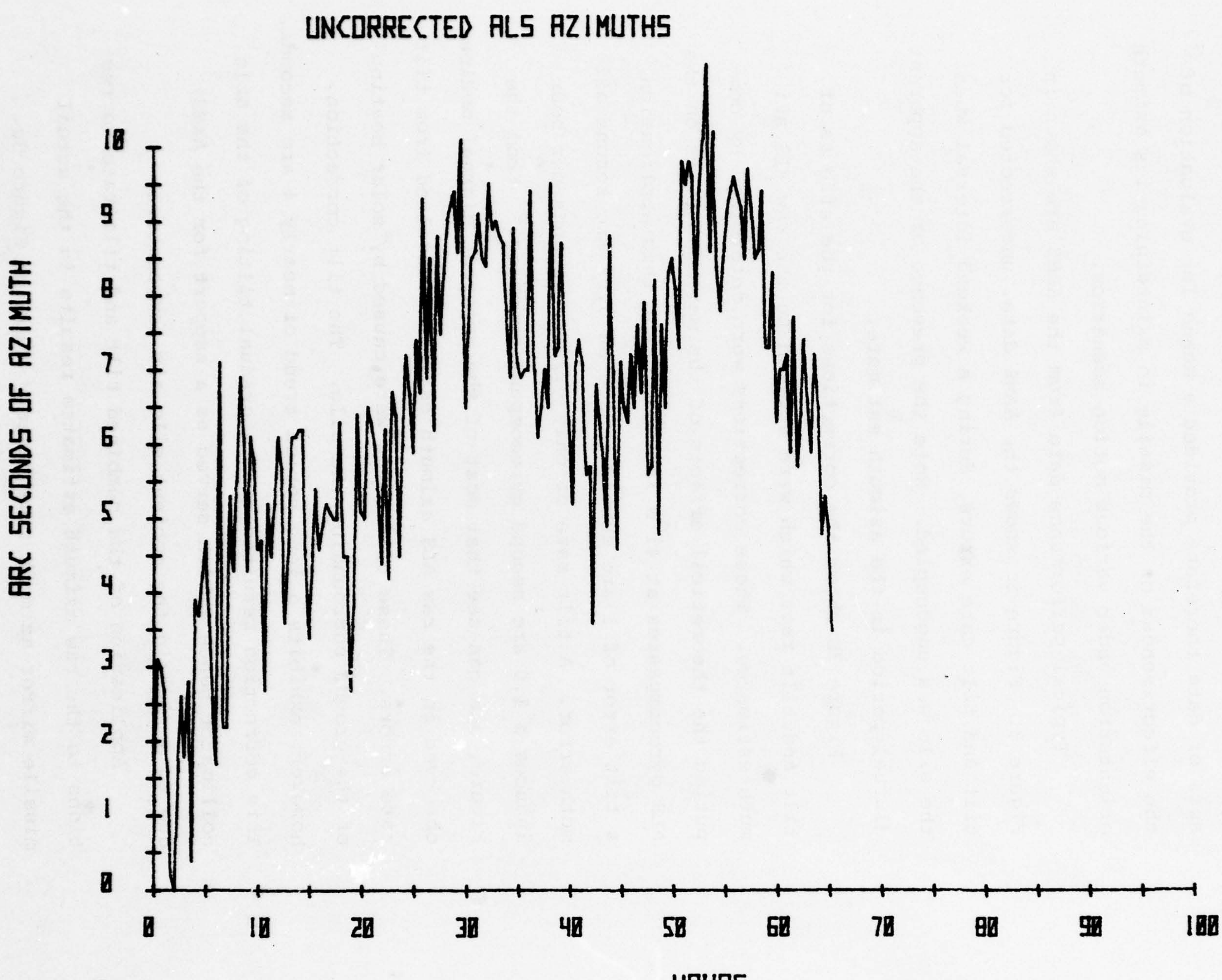

UNCORRECTED ALS AZIMUTHS
ARC SECONDS OF AZIMUTH
0
1
2
3
4
5
6
7
8
9
10
0
10
20
30
40
50
60
70
80
90
100
HOURS

FIGURE 3 (a)

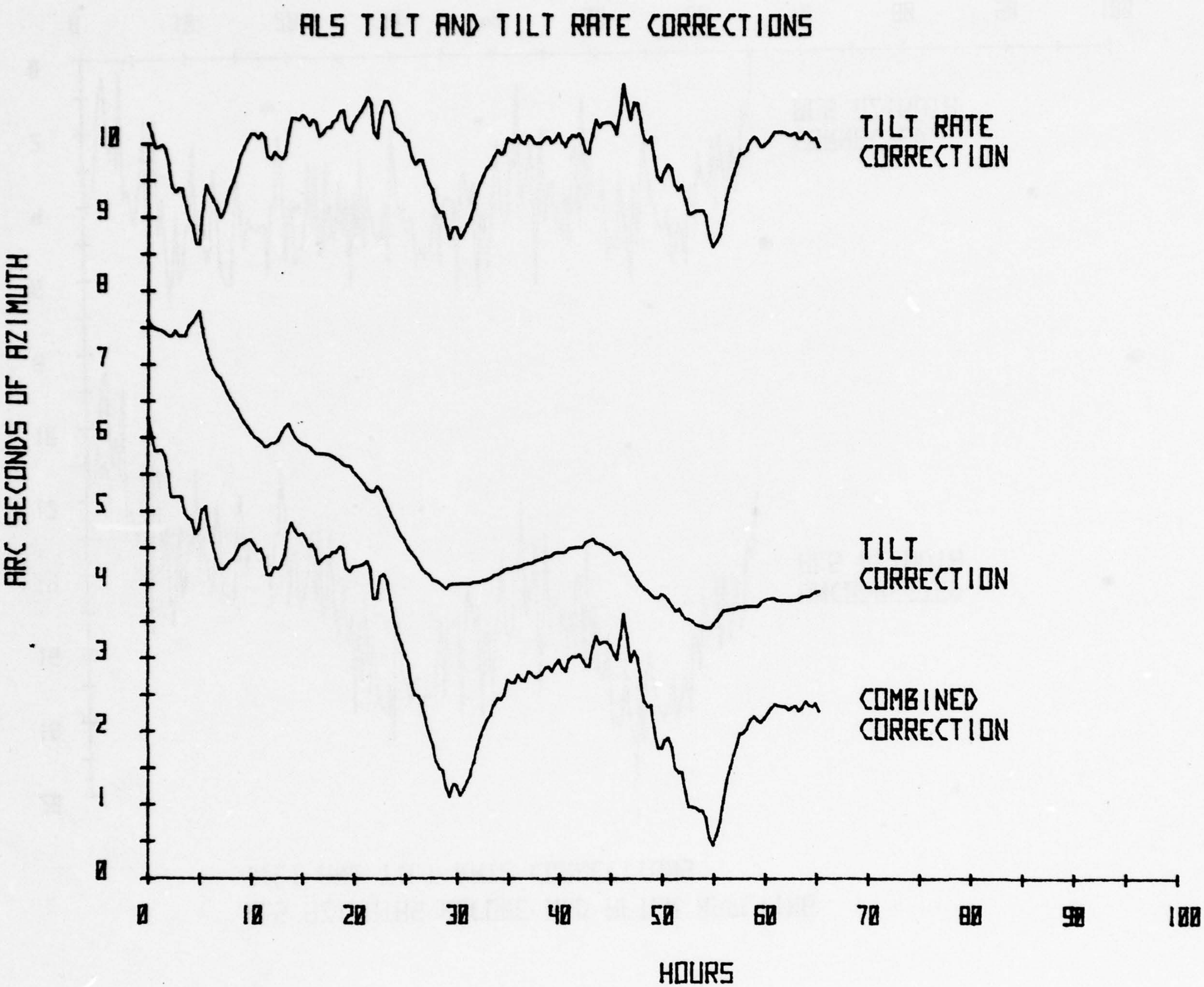

ALS TILT AND TILT RATE CORRECTIONS
ARC SECONDS OF AZIMUTH
0
1
2
3
4
5
6
7
8
9
10
TILT RATE CORRECTION
TILT CORRECTION
COMBINED CORRECTION
0
10
20
30
40
50
60
70
80
90
100
HOURS

FIGURE 3(b)

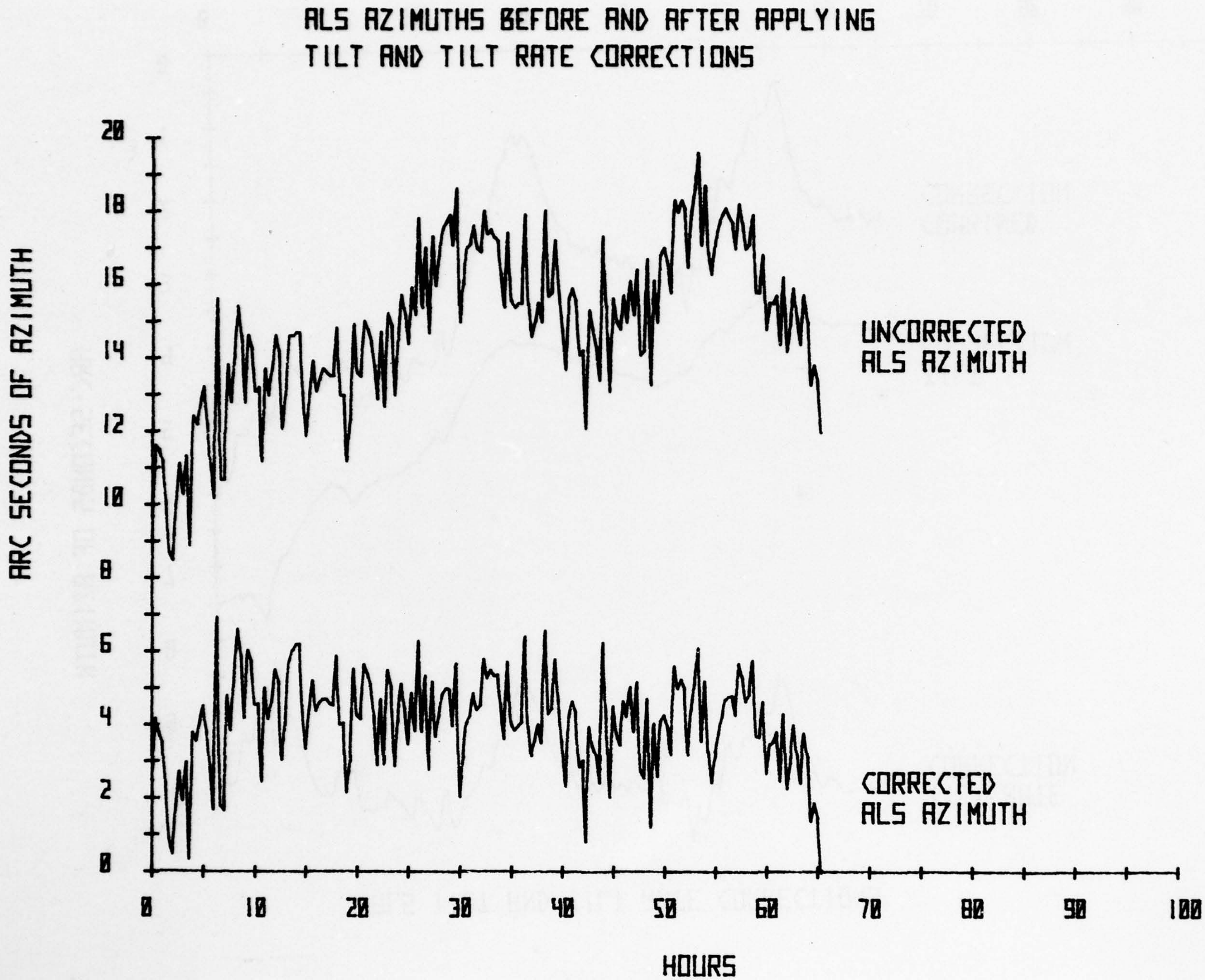

ALS AZIMUTHS BEFORE AND AFTER APPLYING
TILT AND TILT RATE CORRECTIONS
ARC SECONDS OF AZIMUTH
0
2
4
6
8
10
12
14
16
18
20
UNCORRECTED
ALS AZIMUTH
CORRECTED
ALS AZIMUTH
0
10
20
30
40
50
60
70
80
90
100
HOURS

FIGURE 3(c)

Note that the diurnal effects which were apparent in Figure 3a have been removed by applying the corrections.

The validity of applying theoretical tilt and tilt rate corrections to raw ALS azimuth estimates was verified experimentally. A single ALS was placed on a tilt table at Weston Observatory, Weston, Massachusetts. After the ALS had reached thermal stability (24 hours continuous operation), the table was tilted 6.18 arc seconds (600 table counts). The mean values of the ALS azimuths for a period of eight hours before and eight hours after tilting the table were computed. The difference between the mean before and the mean after agreed within 1.8% with the theoretical azimuth change caused by the calibrated tilt.

A similar experiment was conducted to determine the effects of tilt rate. The table was operated through its range in both directions at a known rate. Once again the differences in the means of the azimuths for the periods when the table was being tilted were compared with the theoretical azimuth changes. The agreement was within 3.4% and 0.7% respectively for the two directions. The tilt and tilt rate calibrations are tabulated in Table 2.

4.2 Central Inertial Guidance Test Facility

A forthcoming application of the AAMS is to determine the azimuthal motion characteristics of two azimuth references at the Air Force's Central Inertial Guidance Test Facility (CIGTF), Holloman AFB, New Mexico. For this requirement, the azimuths of two references devices will be monitored simultaneously with the AAMS. The two devices -- a porro prism which is mounted on a granite monolith and a mirror which is mounted on a precision Goerz tilt table -- are separated by over 100 feet in two separate rooms in the basement of the CIGTF Advanced Inertial Test Laboratory (AITL).

Currently, the means for determining the azimuths of these references is through a combination of (1) celestial observations from the roof of the building using a Kern DKM-3 theodolite, (2) double autocollimation through a sight tube to a second DKM-3 theodolite, and (3) a third pointing of the theodolite to the porro prism. Transfer of the azimuth to the Goerz table would require an additional relocation of the theodolite and a series of direction observations between the porro and the Goerz mirror.

By employing the AAMS with autocollimator observations of both the porro and the Goerz mirror during each sequence, the azimuthal motions of both references can be characterized and compared. Azimuthal motions with diurnal periods are of special interest at this facility because of the temperature extremes between day and night. Tilts of several arc seconds have been observed on the granite monolith where the porro prism is mounted. Thus it is reasonable to assume that azimuth changes of this magnitude may also occur.

Table 2. Calibration of Tilt Effects on ALS Azimuth

TABLE TILT* (ARC SEC) OR TILT RATE** (ARC SEC/SEC)	THEORETICAL AZIMUTH CHANGE (ARC SEC)	MEAN ALS AZIMUTH CHANGE (ARC SEC)	DIFF (ARC SEC)	% DIFF (%)
-6.2*	-5.6	-5.7	+0.1	1.8
+0.00160**	+29.7	+30.7	-1.0	3.4
-0.00163**	-30.3	-30.1	-0.2	0.7

*At Weston Observatory ($42^{\circ}23'05''$N Latitude), 1 arc second of tilt = 0.913 arc sec theoretical azimuth error.

**At Weston Observatory, a theoretical azimuth error of 1 arc second results from a tilt rate of 5.39×10^{-5} arc sec/sec.

V. PROPOSED IMPROVEMENTS

A two-year improvement program for the AAMS is presently underway. The program is designed to increase the accuracy and automation of AAMS azimuth determinations.

Current improvements in the system include replacement of d.c. power supplies and installation of tiltmeters on the geosensors. The next phase of the improvement program will expand use of microprocessors. It is planned that the timing and sequencing of the ALS Control Indicator circuits will be replaced by resident LSI-11/2 family components. Thus, the critical parameters of the azimuth determination will be placed under software control, adding greatly to the flexibility and performance of the system.

5.1 Tiltmeters

In addition to the tiltmeter array being used to monitor bending of the AAMS geosensor mounting plate, new tiltmeter units are being installed directly on the geosensor gimbal assemblies.

The design chosen for the AAMS application is a straight line level device. This unique device operates on the principle of straight line translation of a mass with a slight rotation about the direction of travel. The path of the sensing element, being essentially in a straight line, eliminates problems of non-linearity encountered using pendulum-principle devices. Other advantages include durability, high temperature operation and low drift characteristics.

The custom tilt sensing elements designed for the AAMS are capable of detecting a tilt angle of one nanoradian with a long term drift of less than one hundred nanoradians per month.

Mounted on the geosensor gimbal, the effects of microseisms and temperature variations limit the minimum discernable tilt.

The software flexibility of the computerized AAMS will be used to optimize the sampling time of the tilt data.

5.2 <u>Electronics</u>

Studies indicate that substantial internal electrical noise is present on the low voltage supply lines feeding the critical measurement circuits. Unfortunately the nature of the d.c. supply contributes significant switching transients at the frequency of the converter, which in turn is synchronized to the system clock. The result is the presence of noise pulses on nearly every signal path in the ALS electronics. Experiments involving the application of external d.c. to certain control circuits have eliminated much of this noise. Preliminary tests also show a reduction in the variability of the measured azimuth readout when external linear power supplies are substituted.

Thus, in order to insure the quietest operation of the electronic networks, precision linear power packs have been devised to provide all d.c. power for the ALS. These power packs are being integrated with the power control circuits for normal operation.

5.3 Optical Transfer

A considerable improvement in pointing accuracy of the electronic autocollimator has been observed when low velocity air is flowing along the line-of-sight. The tendency for stagnant air to form convection currents which change the refractive index in the air path has led to the use of moving air in sight tubes.

Figure 4 shows the dramatic reduction in angular noise possible with the low velocity air feature over short distances.

The use of sight tubes over distances greater than 20 feet is being investigated. It will be necessary to determine methods of tube support and the effects of internal wall reflection. The method of introducing forced air into the sight tubes and the optimum flow velocity will also be studied.

5.4 Optical Table

For previous field operations, the AAMS was supported by a 1" X 3' X 5' steel plate. This plate was found to be very sensitive to thermal gradients between its top and bottom surfaces. Distortions of several arc seconds of

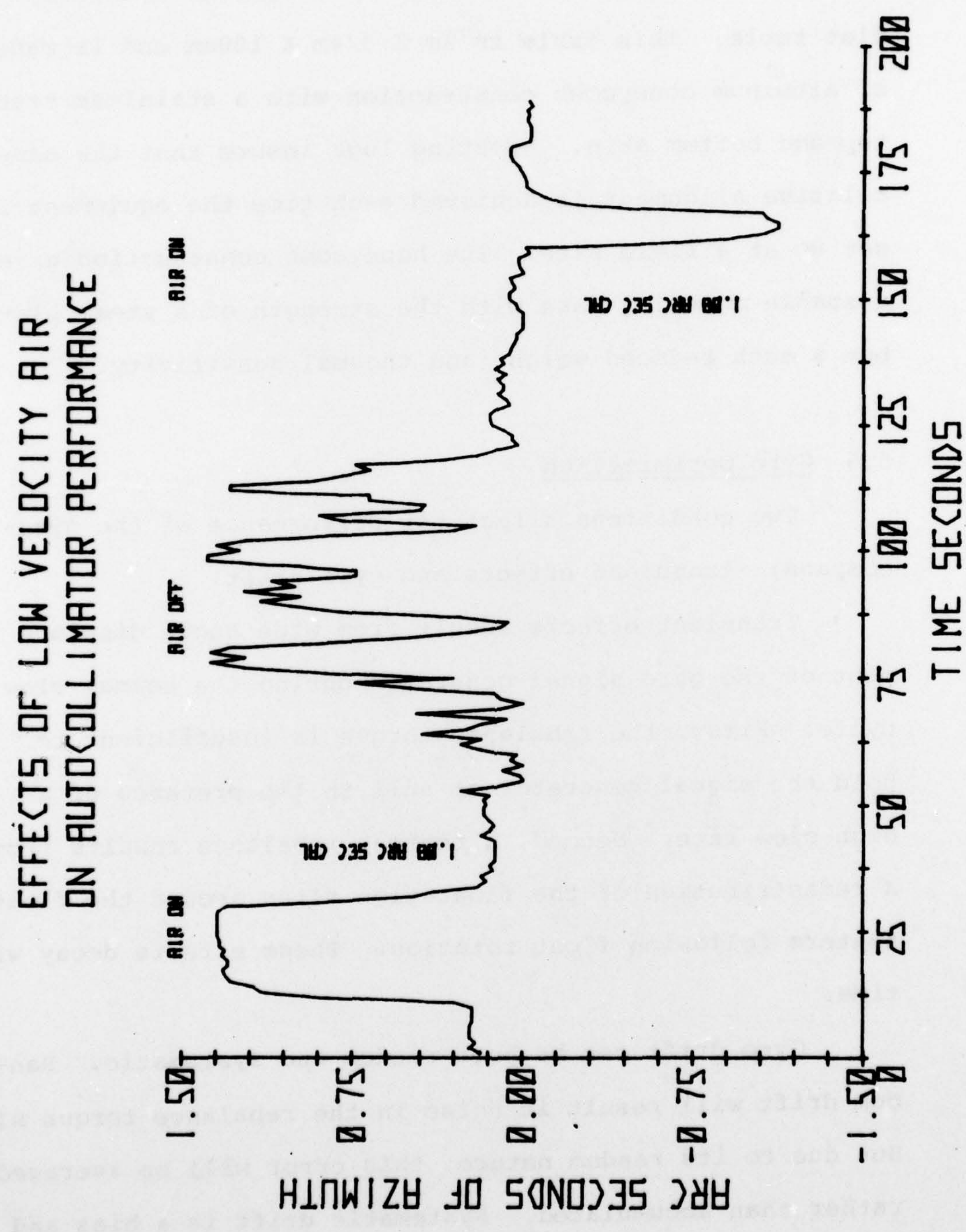

EFFECTS OF LOW VELOCITY AIR
ON AUTOCOLLIMATOR PERFORMANCE
ARC SECONDS OF AZIMUTH
1.50
0.75
0.00
-0.75
-1.50
AIR ON
AIR OFF
AIR ON
1.00 ARC SEC CAL
1.00 ARC SEC CAL
0
25
50
75
100
125
150
175
200
TIME SECONDS

FIGURE 4

tilt resulted from temperature gradients of 0.1°C. Thus, the two geosensors, Goerz Inductosyn, Porro prism and surface tiltmeters are now mounted on a special optically flat table. This table is 1m X 3/4m X 100mm and is made of aluminum honeycomb construction with a stainless steel top and bottom skin. Locating lugs insure that the same relative alignment is achieved each time the equipment is set up at a field site. The honeycomb construction gives a stable mounting base with the strength of a steel plate, but a much reduced weight and thermal sensitivity.

5.5 Gyro Optimization

Two conditions affect the performance of the gyrocompass: transient effects and gyro drift.

Transient effects result from wide angle displace ment of the gyro signal generator during the normal slew cycle. First, the rebalance torque is insufficient to hold the signal generator at null in the presence of a high slew rate. Second, a thermal imbalance results from a redistribution of the floatation fliud around the float heaters following float rotation. These effects decay with time.

Gyro drift can be both random and systematic. Random drift will result in noise in the rebalance torque signal. But due to its random nature, this error will be averaged rather than accumulated. Systematic drift is a bias and will accumulate with time. These effects have been studied to some degree already for similar gyros.[5] However, the specific characteristics of the two ALS gyros now in use are unknown.

The AAMS electronics are designed to allow a wide variation of gyro settling and sampling times. Optimization of sample and slew times will therefore be achieved by using a sufficiently long rest time for transient effects to disappear, while minimizing the integration of drift contributions. These times will be varied during calibration to determine the optimum values for minimum variability of the azimuth data.

5.6 Automation

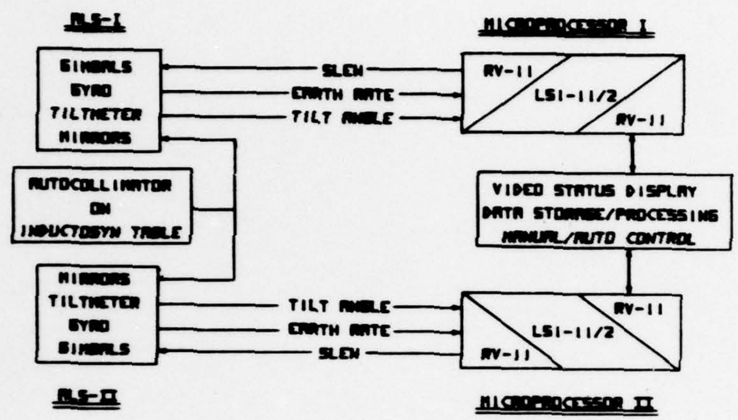
The ALS control indicator contains the measurement and sequencing circuits. Presently, all functions are synchronously locked to the master clock. Once started, the gyrocompass sequence proceeds automatically as dictated by the timing circuits. The two ALS systems are synchronized by a fairly complex electronics package which required frequent maintenance.

The assimilation of logic signals from the geosensor and related sequencing circuits is ideally suited for local microprocessor control. Thus, in the next phase of the system upgrade, command and control of the geosensor and gyro torquer loop will be assigned to dedicated LSI-11/2 microprocessor modules. This will facilitate software control of system functions with flexibility for interactive operation for evaluation and diagnostic procedures. Synchronization of the dual geosensors will be greatly simplified and the reliability of operation improved.

A simplified diagram of the fully automated AAMS is shown in Figure 5. The basic support circuits (gyro spin motor supply, gimbal servo loops, and temperature control) will be retained from the original control indicator units. The LSI-11/2 microcomputer, with memory modules for storage of the four position gyrocompass sequence program, will then be superimposed on the existing circuits. The microcomputer interface with the geosensors and control circuits will be achieved through parallel line interface boards. A local control console will allow for manual operation for calibration and troubleshooting.

The crucial gyro torque-loop signal development will be modified to employ recently developed VFC (voltage to frequency converter) integrated circuitry. The pulse rate proportional to torque current thus generated will go directly into the microcomputer random access memory for azimuth determination.

As shown in Figure 5, the central control function will tie the two channels of the AAMS together functionally. It will contain the bulk of the support electronics, including linear d.c. powerpacks, Inductosyn table drive electronics, autocollimator electronics, control indicators, video data display and switches for manual operation. During normal operation a remote data acquisition system will handle functional control, local plotting and analysis of small segments



PROPOSED SCHEMATIC OF
IMPROVED AAMS

FIGURE 5

of data as well as data storage. The remote facility will incorporate a stand-alone microcomputer, magnetic tape data storage and a printer/plotter.

VI. SUMMARY

The AAMS is an automated inertial azimuth measuring system designed for high accuracy, all-weather azimuth measurements. The unique incorporation of tilt measurements with AAMS azimuth measurements not only improves the accuracy of the AAMS azimuth data, but provides a comprehensive motion history of the observed target at much higher frequencies than traditional celestial azimuth determinations. Automatic angle measurements using an autocollimator on a precise indexing table enable azimuth transfers to multiple targets without introduction of human error.

The AAMS is being further improved to increase its precision and automation. Improvements include replacing noisy electronics with precision linear power packs, improved optics and application of advanced tiltometry hardware and techniques. Resident microcomputers and the latest microprocessor technology will be employed for automatic sequencing and signal processing. The flexibility of software control will enable optimization of operation, data acquisition and processing, thereby fulfilling a wide variety of Air Force needs for precise azimuth measurements.

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